SPECIFICATION

Pyrotechnic Circuit Breaker

BACKGROUND OF THE INVENTION

[0001] The present invention is directed generally to the field of circuit breakers, and more particularly, to a circuit breaker including a pyrotechnic element for breaking the circuit.

[0002] he circuit breakers used in various electrical systems in motor vehicles such as automobiles, trucks, buses, fixed wing aircraft, helicopters, marine vessels and the like, have conventionally employed fuse-type resistor elements that burn out when an excessive level of current passes through the element, causing a break in the circuit.

[0003] Various substitutes for such conventional fuses have also been devised, such as to permit breaking of a circuit in response to abnormal conditions (such as the collision of a vehicle) that would not necessarily create an immediate excessive current load in a fuse. For example, U.S. Patent No. 6,194,988 to Yamaguchi et al. teaches the use of a sort of "hot plate" that is spring-biased against a relatively low melting point fuse section, with the hot plate being heated by an attached igniting device that contains a solid combustion agent; the igniting device is rapidly activated such as in the case of

a collision, heating the hot plate which then melts the adjacent fuse section and (due to the spring bias) drives through the molten fuse section, cutting it out and thereby breaking the circuit. Devices such as that of the '988 patent based on melting that is induced by conducted heat, however, cannot exploit the rapidity of a pyrotechnic ignition because the process of heat conduction is quite slow in comparison to the speed of a pyrotechnic ignition. Such devices can also be relatively complex and costly.

[0004] There are also a number of recent battery cable clamp breaker devices that include a pyrotechnic device (configured to ignite in response to an abnormal condition such as a collision of the vehicle containing the device) that physically drives apart two parts of the clamp or terminal so that they are no longer electrically connected, such as in U.S. Patent No. 5,725,399 to Albiez et al. and U.S. Patent Nos. 5,818,121, 6,144,111, and 6,171,121 to Krappel et al. This type of device is generally capable of deploying quickly, e.g., in the case of a collision so as to reduce the chance of an electrical fire in the damaged vehicle irrespective of whether the conditions would rapidly cause a conventional fuse to blow. Yet such devices are in general a relatively complex, costly, and/or bulky way to provide the function of pyrotechnically-induced circuit breaking. Moreover, such devices do not intrinsically involve a

conventional (i.e., current load-based) fuse, so if it were desired to also retain the conventional function of current load-based breaking in such a circuit breaker, a conventional fuse would need to be added as a distinct additional component, thus rendering the resulting device yet more complicated and costly.

[0005] Finally, U.S. Patent No. 5,877,563 to Krappel et al. teaches various breaker devices in which a pyrotechnic device is used to propel a cutter(s) through a cable(s) or to unplug a connector(s). The '563 patent, however, does not teach either the direct pyrotechnic ablation of any portion of a circuit, the pyrotechnically-driven cutting of a portion of the circuit that is specially formed to be readily cut, or any kind of pyrotechnically-driven breaking of a current load-based fuse in a circuit. Thus the devices taught in the '563 patent are somewhat complicated, and none includes the function of a conventional current load-based fuse.

SUMMARY OF THE INVENTION

[0006] A circuit breaker according to the present invention includes a pyrotechnic igniter and a portion of the circuit that breaks as a result of the ignition of the pyrotechnic igniter.

[0007] In a first aspect of the present invention, the portion of the circuit to be broken by the pyrotechnic igniter may be

specially formed to receive a direct ablation force from the pyrotechnic igniter, such as for example flattened and/or enlarged in a plane perpendicular to the output of the pyrotechnic igniter. Thus, an intermediate cutting device is not required, permitting an advantageously simplified pyrotechnic circuit breaker to be attained.

[0008] In another separate and independent aspect of the invention, the portion of the circuit to be broken by the pyrotechnic igniter may be specially formed to be readily cut in response to an indirect cutting force from the pyrotechnic igniter, such as for example flattened in a plane perpendicular to the output of the pyrotechnic igniter and/or scored. Thus the overall pyrotechnic output force and/or measures to focus that force in order to cut the portion of the circuit are reduced, permitting an advantageously simplified pyrotechnic circuit breaker to be attained.

[0009] In yet another separate and independent aspect of the invention, the portion of the circuit to be broken by the pyrotechnic igniter may be a current load-based fuse. Such fuse can be broken either directly through ablation by the output of the pyrotechnic igniter, or indirectly through cutting by a projectile propelled by the output of the pyrotechnic igniter. In this case, the circuit breaker includes two modes of operation, i.e., current load-based breaking, and breaking

triggered by an electrical signal to the pyrotechnic igniter; yet the circuit breaker can remain an integrated, unitary device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] **Fig. 1** is a perspective, partly cut-away view of an embodiment of a pyrotechnic circuit breaker according to the present invention, utilizing a cutting projectile.

[0011] **Fig. 2** is a transverse sectional view of the embodiment of Fig. 1.

[0012] **Fig. 3** is a lateral sectional view of another embodiment of a pyrotechnic circuit breaker according to the present invention, not utilizing a cutting projectile, but a focused ignition output.

[0013] **Fig. 4** is a lateral sectional view similar to that of Fig. 3, but depicting an alternative embodiment in which the portion of the circuit to be broken has an enlarged impact area, which may optionally be used with a cutting projectile.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0014] Referring to **Figs. 1** to **3**, a preferred embodiment of a pyrotechnic circuit breaker **20** in accordance with the present invention may include an upper housing **22** and a lower housing **30**, which may be made of metal, ceramic, or polymer, preferably a suitable high-strength, high-temperature polymer thermoplastic or thermoset such as Ryton®, Amodel®, Ultem®, Phenolic®, Zytel®

and the like. The housing may preferably be constructed as an integral, one-piece, injection molded-in-place housing, preferably created by joining together two or more components. Optionally, a polymer overmolding (preferably selected for beneficial cost, formability, and electrical insulation characteristics) or a superstructure or skeleton of metal may be utilized for added strength. A pyrotechnic igniter assembly **32** is held securely within the upper housing **22**, and the portion of the electrical circuit to be broken by the output of the pyrotechnic igniter assembly **32** is situated between the upper housing **22** and the lower housing **30** and may preferably take the form of a bolt-on fuse strip **24** (which includes bolt holes **26** for securing the device to a terminal or the like) (or **24'** in **Fig. 3**). The pyrotechnic igniter assembly **32** may preferably be any suitable reliable, low-cost pyrotechnic device such as an automotive airbag initiator. The pyrotechnic igniter assembly **32** is thus initiated by the issuance of an appropriate electrical signal through its leads, which, for example in the case of an automobile, are preferably connected to the electronic control unit of the automobile's occupant restraint system.

[0015] As can be seen, the pyrotechnic igniter assembly **32** is oriented so that its output is directed through a passage to the bolt-on fuse strip **24**, generally perpendicularly to the axis of

the bolt-on fuse strip **24**. Vents (not shown) through either or both halves of the housing may also optionally be provided to safely release the hot gases created by ignition of the pyrotechnic igniter assembly **32**. Increasing the diameter of the passage between the pyrotechnic igniter assembly **32** and the bolt-on fuse strip **24** tends to increase the required output of the pyrotechnic igniter assembly **32** and thus may necessitate a stronger housing (both of which tend to increase manufacturing cost); however, the passage's diameter cannot be decreased arbitrarily as that may undesirably reduce the ability of the housing to withstand the flow of high or excessive current through the bolt-on fuse strip **24**. The heat tolerance of the housing may be improved so as to permit further reduction of the diameter of the passage, however, such as by forming the housing of a thermoset type polymer, or by adding heat stabilizers or anti-aging additives to a suitable thermoplastic, or by using a cast metal such as zinc or aluminum (although in that case, electrical insulation must be provided between the housing and the fuse).

[0016] Optionally (as depicted), a projectile **34** may be provided between the pyrotechnic igniter assembly **32** and the bolt-on fuse strip **24** or other such portion of the electrical circuit that is to be broken, and if so, the projectile **34** can preferably be integrally molded into the upper housing **22** as is shown. Upon

ignition of the pyrotechnic igniter assembly **32**, the projectile **34** breaks free and is propelled into the bolt-on fuse strip **24**, with its pointed front portion facilitating cutting of the bolt-on fuse strip **24**. It is noted that the projectile **34** does not necessarily need a point or sharp edge, because the action may primarily be that of shearing the **24** fuse strip. Also, the projectile **34** can made be of the same material as the housing, even if it is polymer, because the action may primarily be a function of the velocity of the projectile **34** rather than its strength. Thus, the projectile **34** may be monolithically molded as part of the housing, eliminating a separate part and the associated cost and scrap, and increasing reliability. In that case, the material connecting the projectile **34** to the rest of the housing preferably may have a cross-section and material strength selected so as to break upon output with enough energy to accelerate the projectile **34** to the velocity required to break the fuse strip **24**, and is preferably configured so that an edge is formed upon separation of the projectile **34** from the housing that may provide a seal to the projectile **34** as it travels through the fuse strip **24**. When the projectile **34** (which is non-conductive) breaks the fuse strip **24**, it pushes the fuse strip **24** into the rupture area **28** (see Fig. 2), preferably locking the broken fuse strip **24** section in place so that it cannot inadvertently re-make the circuit.

[0017] Referring to **Fig. 2** in particular, it can be seen that a rupture area **28**, which is an empty cavity, is provided below the bolt-on fuse strip **24** between the standoff in the sides of the lower housing **30**. As noted, the rupture area **28** accommodates the resulting projection of the adjacent portion of the bolt-on fuse strip **24** when impacted by the output of the pyrotechnic igniter assembly **32** or the optional projectile **34**. The rupture area **28** can also help reduce the heat conducted into the upper housing **22** and lower housing **30** when the bolt-on fuse strip **24** experiences an excessive current load.

[0018] Referring to **Fig. 3** in particular, this embodiment reduces ignition charge size for a given sized fuse by focusing ignition gases around the fuse portion to be severed. This increases the local temperature and severs the fuse by applying drag forces across the thickness of the fuse generated by high-speed ignition gases and focused force of the ignition exhaust. The housing is preferably designed to follow the contours of the fuse such that the ignition gases can only pass through a narrow aperture (clearance) around the fuse exerting pressure to break it. The bolt-on fuse strip **24'** has a thickness and minimum fuse width that correspond to the rated amperage of the particular fuse, as is known in the art. Bolt-on fuse strips are well-known for use in breaking a circuit under high current override conditions. The output of the pyrotechnic igniter assembly **32**,

and the configuration of the upper housing **22**, lower housing **30**, projectile **34** (if any) and rupture area **28**, should be designed to accommodate the thickness of whatever fuse may be chosen for use in the circuit breaker, and to ensure reliable breaking of the fuse upon activation of the pyrotechnic igniter assembly **32**. Where projectile is not used, the clearance between the periphery of the fuse strip and the adjacent perimeter of the rupture area has a significant effect on the rupturing impact of the pyrotechnic output on the fuse (with less clearance increasing the rupture force exerted). (Although the depicted preferred embodiments utilize a fuse as the portion of a circuit that is formed to be readily broken, which is preferable, it does not necessarily have to be a fuse).

[0019] As shown in **Fig. 4**, an alternate bolt-on fuse strip **24''** can be provided with an enlarged impact area **38** that reduces the amount of energy that must be produced by the pyrotechnic igniter assembly **32** in order to ablate or otherwise break the bolt-on fuse strip **24''**, thus permitting (depending on the embodiment) the use of a lower cost pyrotechnic igniter assembly than the one depicted in Fig. 3. This acts like a "force accumulator" and absorbs force generated from the ignition exhaust, allowing for a smaller ignition charge to sever a given sized fuse. Alternately, if the optional projectile **34** is omitted, the enlarged impact area **38** can be employed to receive

more of the output energy of the pyrotechnic igniter assembly **32** so that a larger igniter is not needed.

[0020] It has been determined that the embodiment of the invention described here can be configured to result in breakage of the circuit in about 0.1 to 5ms, e.g., 1ms, after issuance of a signal to pyrotechnic igniter assembly **32**. Such a fast response time can help reduce the potential for buildup of heat in wiring and circuitry such as in a vehicle that has experienced a collision, prevent electrocutions, and stop fast-moving machinery or cutting apparatus or other abnormal condition such as in industrial safety systems.

[0021] If desired, electronic circuitry (not shown) may also be incorporated into the pyrotechnic circuit breaker **20**, for example in applications where actuation of the igniter may require a secure digital signal for security or safety reasons, e.g., in the case of actuation by law enforcement or military personnel in the event of theft, pursuit, et cetera. If included, such circuitry could also be configured to monitor (based on, e.g., inductive field, temperature, or other desired means) the condition of the fuse itself to determine if a condition is present that warrants breaking the circuit. In such case, if suitable current-sensing means are employed, the portion of the circuit broken by the pyrotechnic igniter assembly need not be a fuse but instead can simply be an

ordinary low resistance portion that is formed (e.g., by flattening, widening, and/or scoring) to be readily ablated or cut.

[0022] Although the foregoing description has described the action of the pyrotechnic igniter assembly as sufficient to fully ablate or cut the bolt-on fuse strip, other embodiments can readily be conceived in which the combination of heat, shock loading, and output gas pressure from the igniter breaks, weakens, or damages the fuse so as to decrease the amount of current required to sever the fuse (or cause it to break more rapidly at its rated current). It is also possible that the pyrotechnic igniter assembly can be used as the main actuator of the fuse in response to a command signal as well as in response to an excessive current load, such as by choosing a configuration and composition of the pyrotechnic igniter assembly whereby the igniter auto-ignites in response to heat generated by the fuse during excessive current load.

[0023] As will be readily apparent to one in the art, there are a number of applications in which suitable embodiments of a pyrotechnic circuit breaker according to the present invention may be employed. Considering just automotive applications by way of example, suitable embodiments may be used in an automobile to rapidly cut power in the case of a collision and thus reduce the risk of electrical fire or damage to electrical

components. Circuitry generally similar to that used in safety system controllers could also be incorporated to monitor one or more conditions and when appropriate provide a command to the initiator to break the circuit, for example, a predetermined amount of time after the initial sensing of a collision. As another example, suitable embodiments of the present invention may be employed to disable an automobile (such as in response to a command transmitted by the owner, security service vendor, or government personnel) in the case of theft or unlawful operation of the vehicle. In such case, other measures known in the art may also be employed in conjunction so as to reduce the likelihood of immediate loss of control of the vehicle in response to such a command, et cetera. Another application is industrial equipment and personnel safety systems, such as safety curtains, emergency brakes for fast-moving rotary or linear machinery, cutting apparatus/blades, electrocution prevention, quick disconnects, et cetera.

[0024] Thus, although the present invention has been described in the context of one particular preferred embodiment, one skilled in the art will appreciate that numerous variations, modifications, and other applications are also within the scope of the present invention. For example, the present invention can be used in any suitable application in which there is a need for remote or automatic cutting of power in a rapid manner, such

as in military or commercial vessels or aircraft (e.g., in case of enemy attack), commercial building power control panels and oil pipeline pumping stations (e.g., in an emergency such as an earthquake or terrorist attack), munitions or explosive devices (e.g., to disarm associated electronic circuitry), industrial safety curtains and high speed equipment (e.g., as a rapid power disconnect), and a number of other applications. Thus, the foregoing detailed description of preferred embodiments is not intended to in any way limit the invention, which is limited only by the following claims and their legal equivalents.